

**IEA
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REPORT
1997**



International
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Agency



R&D
Wind

IEA WIND ENERGY ANNUAL REPORT 1997

International Energy Agency (IEA)
Executive Committee for the

**Implementing Agreement for
Co-operation in the
Research and Development
of Wind Turbine Systems**

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Cover Photo

The Electricity Corporation of New Zealand Brooklyn Research and Demonstration wind turbine generator above Wellington, New Zealand.

The twentieth IEA Wind Energy Annual Report reviews the progress during 1997 of the activities in the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems under the auspices of the International Energy Agency (IEA). The agreement and its program, which is known as IEA R&D Wind, is a collaborative venture between parties from 17 IEA member countries and the European Commission.

The International Energy Agency, founded in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to collaborate on international energy programs, carries out a comprehensive program about energy among 24 industrialized nations.

This report is published by the National Renewable Energy Laboratory (NREL) in Colorado, United States, on behalf of the IEA R&D Wind Executive Committee. It is edited by P. Weis-Taylor with contributions from Australia, Canada, Denmark, Finland, Germany, Greece, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom, and the United States.

Raj RANGI
Chair of the
Executive Committee

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Secretary to the Executive
Committee

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I. EXECUTIVE SUMMARY



INTRODUCTION

IEA's commitment to wind energy dates back to 1977, when the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems (IEA R&D Wind) began. Since then, worldwide deployment of wind energy has expanded significantly. As IEA R&D Wind completes its 20th year, deployment of wind power has risen more than 200% representing an annual growth rate exceeding 33%.

Leadership in the manufacture and deployment of wind turbine generators has been assumed by the European wind industry. Several manufacturers in Europe are now building and shipping new turbines at the rate of one megawatt per day. Furthermore, in efforts to reduce pollution, many European countries have established high purchase prices to suppliers for electricity from wind turbines and offer attractive financial incentives. These factors make the European market for wind turbines very promising.

In many other nations wind power deployment is also increasing. Countries around the world are building new grid-connected wind power plants and off-grid power projects. One leader among non-OECD countries is India, where installed wind power has grown to about 930 MW. The IEA estimates that wind power installations worldwide will grow from 2 gigawatts (GW) in 1990 to more than 12 GW by the end of 2000.

The four main objectives of IEA R&D Wind have made it an important force in the research and development of wind energy. IEA R&D Wind has activities regarding: Advanced technology research; State-of-the-art assessments; Information exchange; and Extended cooperation to increase the involvement of industry and utilities and nonmember countries. In

addition, IEA is expanding from Research, Development, and Deployment (R, D&D) programs to include tracking of implementation incentives offered by its member countries.

At present, 19 organizations from 17 countries and the European Commission participate in IEA R&D Wind. Australia, Austria, Canada, Denmark, Finland, Germany, Greece, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Spain, Sweden, the United Kingdom, and the United States are now members. Recently there has been increasing interest in IEA participation from both Organization for Economic Co-operation and Development (OECD) and non-OECD countries. This interest is being encouraged and prospective members attend IEA Wind Executive Committee (ExCo) meetings to observe first-hand the benefits of participation.

NATIONAL PROGRAMS

The national wind energy programs of the participating countries are the basis for the IEA R&D Wind collaboration. These national programs are directed toward the evaluation, development and promotion of wind energy technology. They are concerned with work at home and in other countries. A summary of progress in each country is given in the following Chapters.

COLLABORATIVE ACTIVITIES

Participants in the IEA R&D Wind Agreement are currently working on four Tasks, also called Annexes, and several additional Tasks are being planned. To date, 11 Tasks have been successfully completed and one Task has been deferred indefinitely. The level of effort on a Task is typically the equivalent of several people working for a period of two or three years.

Some Tasks have been extended to continue their work. The projects are either cost-shared and carried out in a lead country, or task-shared, when the participants contribute in-kind, usually in their home organizations, to a joint program coordinated by an Operating Agent. Complete reviews of the progress in each active Task are given in following Chapters. A brief account of the status of Tasks follows here. To obtain more information about these activities, contact the Operating Agent.

Task XI - Base Technology Information Exchange

Operating Agent: Department of Fluid Mechanics of the Technical University of Denmark

The main activities of this task are to: Prepare documents in the series "Recommended practices for wind turbine testing and evaluation;" Undertake Joint Actions in specific research areas where a periodic exchange of information is considered necessary; and Organize Topical Expert Meetings. The original Annex expired in 1997. Discussions are underway to extend authorization for this work.

Recommended Practices

Volume 10: Noise Emission Measurements and Volume 9: Lightning Protection of Wind Turbine Generator Systems and they were published in 1997.

Joint Actions

The 11th symposium within the Joint Action on Aerodynamics of Wind Turbines was held in Petten, Netherlands in 1997. IEA also supported a conference on Deployment of OffShore Wind Energy Systems held in Maddalena, Italy. A key topic was the presentation and discussion of results from Annex XIV Field Rotor Aerodynamics. The 5th Symposium within the Joint Action on Fatigue, will

take place at Delft University, the Netherlands in 1998.

Under Joint Actions, Topical Experts Meetings are held. The 29th Meeting of Experts on Aero-acoustic Noise of Wind Turbines: Noise Prediction Models was held in Milano, in 1997. The 30th Meeting of Experts On the State-of-the-Art on Power Performance Assessments for Wind Energy Conversion Systems was held in 1997 in Athens, Greece.

Planning took place for an Expert Meeting on a possible World Wind Atlas to be held in 1998 at RISØ, Denmark.

Task XIV - Field Rotor Aerodynamics

Operating Agent: Netherlands Energy Research Foundation - ECN, the Netherlands

The work of this Task was documented in 1997 in a final report *Final Report of IEA Annex XIV: Field Rotor Aerodynamics*. This joint research effort involved five laboratories in four countries and coordinated full-scale aerodynamic tests on wind turbines. As a result of the four years of work, a well-documented database is available on CD-ROM and is accessible on an ftp site at ECN.

TASK XV - Annual Review of Progress in the Implementation of Wind Energy by the Member Countries of the IEA

Operating Agent: Energy Technology Support Unit (ETSU), United Kingdom

Arising from a review of the strategic plan, this Task was initiated in 1995. The objective is to produce an annual review giving an overview of the progress in the commercial deployment of wind turbine systems in the IEA member countries participating in this Agreement. The review will be in a form suitable for presentation to decision makers in government, planning authorities, the electricity supply industry, financial institutions and the wind industry. The

aim is to identify major trends in initiatives and attitudes which are likely to be of interest to decision makers. Key topics will include government initiatives, market growth, progress towards national targets, economic trends, progress in addressing environmental issues and public reaction.

Three annual reviews have been completed.

TASK XVI - WIND TURBINE ROUND ROBIN TEST PROGRAM

Operating Agent: National Renewable Energy Laboratory - NREL, United States

The objectives of this program are to validate wind turbine testing procedures, analyze and resolve sources of discrepancies, and improve the testing methods and procedures. A standard turbine will undergo tests at four different sites around the world. Preparation for testing includes drafting test plans, initiating anemometer wind tunnel calibrations, and initiating site calibration measurements. Anemometers from eight countries have been calibrated in ten wind tunnels. NREL and RISØ completed site calibration measurements, while the Italian and Greek participants plan to complete these in 1998.

Three standard turbines underwent tests in 1997. One at Canada's Atlantic Wind Test Site, one at the United States NREL National Wind Technology Center, and one in Denmark at RISØ. A status meeting was held in Greece late in 1997 to continue formalizing the test plan.

EXECUTIVE COMMITTEE ACTIVITIES

Officers

R. Rangi (Canada) and F. Avia (Spain) served as Chair and Vice-Chair during 1997. At the fall meeting, they were reelected to another one-year term.

Participants

In 1997, Mexico signed the R&D Wind Agreement, bringing total membership to 19 organizations participating. See Appendix B for an updated list of Members and Alternate Members. During the year the Executive Committee invited Brazil, Portugal, and China to attend ExCo meetings as observers.

Meetings

The Executive Committee normally meets twice a year for members to review ongoing tasks; report on national wind energy research, development, and deployment activities (R, D&D); plan and manage cooperative actions under the Agreement.

The 39th ExCo meeting was held on May 6-8, 1997 in Golden, Colorado, U.S.A. There were 23 participants representing 12 of the 19 contracting parties.

Operating Agents reported on progress since the last meeting. Annex XI Base Technology Information Exchange will expire at the end of 1997 unless the ExCo decides to extend it for two more years. Annex XIV Field Rotor Aerodynamics has produced a final report which will be available soon. A new Annex to continue the work and expand the database was proposed. Annex XV Annual Review of Progress in the Implementation of Wind Energy by the Member Countries of the IEA was presented. Japan joined the other participants of this Annex. Annex XVI Round Robin Test Program was extended for six months. Converting turbines to 50 Hz caused a delay, so a 6-month extension until October 1998 was approved. A new Annex XVII Data Base on Wind Characteristics was discussed.

A final report was presented by the Task Force on Non-OECD Countries' Participation. This internal document will provide direction for the Strategic Plan of the Implementing Agreement for Co-operation in the Research and Development of

Wind Turbine Systems, which is under development.

The IEA Wind Energy Newsletter is now available on the World Wide Web at <http://www.eren.doe.gov/ieawind/>. Approximately 1,400 paper copies of the Newsletter were distributed.

A brochure titled Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems was reviewed in draft form.

The Secretary offered her resignation and a search committee was formed to select a replacement.

On May 9, 1997 the Committee visited the National Wind Technology Center, the U.S. Department of Energy's wind testing and development facility in Golden, Colorado.

The 40th meeting was held on November 26 and 27 in Rotorua, New Zealand. The Committee approved the 1998 budget. At this meeting Mexico attended as a new participant in the agreement. An invited guest attended from India where installed wind power capacity has grown to about 930 MW. The Newsletter editor gave notice he is retiring. A subcommittee was formed, headed by the Vice Chair, to review the purpose, scope, and frequency of the Newsletter.

The Executive Committee approved the Secretariat Budget after discussion of the uses of a possible budget surplus.

The first regional meeting to disseminate information on wind energy technology and deployment for business took place in conjunction with the ExCo meeting in New Zealand. The meeting was sponsored by the New Zealand power utility ECNZ, by the New Zealand Wind Energy Association, and by the IEA Wind Energy ExCo. About 60 people representing utili-

ties, universities, and industry participated.

Progress reports were presented for the Annexes. A proposal is being prepared to continue Annex XI Base Technology Information Exchange beyond 1998. Annex XIV Field Rotor Aerodynamics was completed in 1997. The Committee voted to use ExCo funds to publish the 3-year report from Annex XV Annual Review of Progress in the Implementation of Wind Energy by the IEA Member Countries. The report would be publicly available. Round Robin Testing under Annex XVI is progressing in Denmark, Canada and the U.S. It is hoped that delays due to technical issues can be recovered to move the project back on schedule.

A proposal was presented for a new Annex XVII Database on Wind Characteristics. Another proposal was presented to extend Annex XIV Field Rotor Aerodynamics or begin a new Annex to maintain and make available an Aerodynamic Database. Another new Annex regarding turbines operating in high wind regimes was discussed.

A draft of the new Strategic Plan was reviewed at the ExCo meeting and will be approved at the 41st meeting.

A new secretary was selected and approved by the ExCo to begin work on January 1, 1998.

On November 28, the Committee visited the Diffuser Augmented Wind Turbine Test Site.

IEA Wind Energy Newsletter

In 1997 two issues of the Newsletter were published, reviewing the progress of the Tasks and the wind energy activities in the member countries. The Executive Committee acts as the editorial board for the Newsletter with a technical editor overseeing production.

II. IEA R&D WIND PROGRAM

CHAPTER 1

The Implementing Agreement

The IEA cooperation in wind energy began in 1977 when The Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems was written. Referred to as IEA R&D Wind for short, this agreement has been signed by 17 countries and the European Commission. IEA R&D Wind currently governs the cooperation of 19 organizations, called contracting parties, designated by these 17 countries and the European Commission. Contracting parties participating in activities for 1997 are listed in Table 1.1.

The objectives of IEA R&D Wind are to exchange information on the planning and execution of national large-scale wind system projects and to undertake collaborative R&D projects, called Tasks.

Overall control of information exchange and the R&D Tasks is vested in the Executive Committee (ExCo). The ExCo consists of a Member and an Alternate Member from each contracting party that has signed the Implementing Agreement. Most countries are represented by one contracting party, mostly government departments or agencies. Some countries have more than one where each contracting party has one representative. Member

Table 1.1 Contracting Parties to the Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems—1997.

Australia	Hydro Electric Corporation
Austria	The Republic of Austria
Canada	Natural Resources Canada
Denmark	Risø National Laboratory
European Commission	The Commission of the European Communities
Finland	The Technical Research Centre of Finland (VTT Energy)
Germany	Forschungszentrum Jülich GmbH
Greece	The Ministry of Industry/Energy and Technology (CRES)
Italy	ENEL S.p.A. and ENEA Cassaccia
Japan	The Government of Japan
Mexico	IIE
Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM)
New Zealand	The Electricity Corporation of New Zealand Ltd.
Norway	The Norwegian Water Resources and Energy Administration (NVE)
Spain	Instituto de Energías Renovables (IER) of the Centro de Investigación; Energetica Medioambiental y Tecnológica (CIEMAT)
Sweden	Energimyndigheten
United Kingdom	AEA Technology plc
United States	The U.S. Department of Energy

Table 1.2 Participation per Country in Current Tasks. OA indicates Operating Agent.

COUNTRY	TASK			
	XI Technology information	XIV Field rotor aerodynamics	XV Annual wind energy review	XVI Round robin test program
Australia	x			
Canada	x			x
Denmark	OA	x	x	x
European Commission	x		x	
Finland	x			
Germany	x		x	
Greece	x		x	x
Italy	x		x	x
Japan			x	
Netherlands	x	OA	x	
New Zealand	x		x	
Norway	x		x	
Spain	x			
Sweden	x		x	
United Kingdom	x	x	OA	
United States	x	x	x	OA

countries also share the cost of administration for the governing body of the Agreement, the ExCo. The ExCo meets twice each year to exchange information on their respective country R&D programs, to discuss work progress on various Tasks, and to plan future activities. Decisions are reached through consensus.

The R&D Tasks performed under IEA R&D Wind are approved by the ExCo as Annexes to the original Implementing Agreement. (They are sometimes referred to as Annexes.) Each Task is managed by an Operating Agent, usually one of the contracting parties in the IEA R&D Wind agreement. The level of effort varies for each task. Some tasks involve only information exchange and require each country to contribute less than 0.1 person year

of work. Other tasks involve test programs requiring several people working over two or more years to complete. Some of these R&D projects are “task shared” by each country performing a subtask; other projects are “cost shared” by each country contributing to the budget for a designated lead country to perform the task. The technical results of tasks are shared among participating countries.

Current tasks and participating countries are listed in Table 1.2.

All tasks undertaken to date are listed in Table 1.3.

Table 1.3 IEA R&D Wind Tasks Defined in Annexes to the Implementing Agreement.

Task I	Environmental and meteorological aspects of wind energy conversion systems Operating Agent: The National Swedish Board for Energy Source Development Completed in 1981.
Task II	Evaluation of wind models for wind energy siting Operating Agent: U.S. Department of Energy - Battelle Pacific Northwest Laboratories Completed in 1983.
Task III	Integration of wind power into national electricity supply systems Operating Agent: Kernforschungsanlage Jülich GmbH, Germany Completed in 1983.
Task IV	Investigation of rotor stressing and smoothness of operation of large-scale wind energy conversion systems Operating Agent: Kernforschungsanlage Jülich GmbH, Germany Completed in 1980.
Task V	Study of wake effects behind single turbines and in wind turbine parks Operating Agent: Netherlands Energy Research Foundation Completed in 1984.
Task VI	Study of local flow at potential WECS hill sites Operating Agent: National Research Council of Canada Completed in 1985.
Task VII	Study of offshore WECS Operating Agent: UK Central Electricity Generating Board Completed in 1988.
Task VIII	Study of decentralized applications for wind energy Operating Agent: UK National Engineering Laboratory Technically completed in 1989. Final report published in 1994.
Task IX	Intensified study of wind turbine wake effects Operating Agent: UK National Power plc Completed in 1992.
Task X	Systems interaction Deferred indefinitely.
Task XI	Base technology information exchange Operating Agent: Department of Fluid Mechanics, Technical University of Denmark Continuing through 1996 and 1997.
Task XII	Universal wind turbine for experiments (UNIWEX) Operating Agent: Institute for Computer Applications, University of Stuttgart, Germany Completed in 1994. Final report published in 1995.
Task XIII	Cooperation in the development of large-scale wind systems Operating Agent: National Renewable Energy Laboratory (NREL), USA Completed in 1994. Final report published in 1995.
Task XIV	Field rotor aerodynamics Operating Agent: Stichting Energieonderzoek Centrum Nederland (ECN), the Netherlands Continuing through 1996.
Task XV	Annual review of progress in the implementation of wind energy by the member countries of the IEA Operating Agent: ETSU, on behalf of the United Kingdom To be completed in 1998.
Task XVI	Wind turbine round robin test program Operating Agent: the National Renewable Energy Laboratory (NREL), United States To be completed in 1998.

CHAPTER 2

Task XI - Base Technology Information Exchange

The objective of this Task is to promote wind turbine technology by cooperative activities and information exchange on R&D topics of common interest. Over the ten years since Task XI (also known as Annex XI) was initiated, 30 volumes of proceedings from expert meetings, six revised editions of Recommended Practices, and three new recommendations have been published. In addition, proceedings from symposia on topics of interest have been published. The original Annex expired in 1997. Discussions are underway to extend authorization for this work.

The Base Technology Information Exchange task includes activities in two subtasks. The first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, the Experts Group on lightning protection of wind turbine generator systems drafted a document published in 1997. Also published in 1997 were the documents drafted by the Experts Group on point wind speed measurements and the Experts Group on noise emission measurements.

The second subtask is to conduct joint actions in specific research areas designated by the IEA R&D Wind Executive committee. The Executive Committee sets up Joint Actions in research areas of current interest, where a periodic exchange of information is deemed necessary. So far Joint Actions have been initiated in *aerodynamics of wind turbines*, *fatigue of wind turbine blades*, and *deployment of offshore wind systems*. In each of these topic areas symposia and conferences have been held.

In 1997, the 11th Symposium within the Joint Action on *aerodynamics of wind turbines* was held in Petten, Netherlands. The key topic was the presentation and discussion of the results from Annex XIV, Field Rotor Aerodynamics. There were 15 participants from 7 countries. Fourteen papers were presented. IEA also supported a conference on *deployment of offshore wind energy systems* in Mediterranean and European seas organized by ENEA (Italy) and held in Maddalena, Italy. Preparations were made for the 5th Symposium within the Joint Action on *fatigue of wind turbine blades*. This Symposium will take place at Delft University, the Netherlands in 1998.

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA R&D Wind Executive Committee. In 1997, the 29th Meeting of Experts on Aero-acoustic Noise of Wind Turbines: Noise Prediction Models was held in Milano. In addition, the 30th Meeting of Experts, held in Athens, Greece, addressed the state of the art on power performance assessments for wind energy conversion systems. There were 14 participants from 6 countries and 13 presentations were made. Proceedings from topical expert meetings are called Meetings of Experts. They can be obtained by contacting the Operating Agent.

A preliminary planning meeting was held at NREL to prepare a Topical Expert Meeting to precede and prepare a possible new annex - World Wind Atlas. At the planning meeting representatives from NREL and RISØ agreed on the format of the Expert Meeting, and arranged for an introductory note to be prepared. The meeting is scheduled for October 1998 at RISØ, Denmark.

Table 2.1 List of Documents in the Series *Recommended Practices for Wind Turbine Testing and Evaluation*.

VOLUME	TITLE	1ST ED.	2ND ED.	3RD ED.
1	POWER PERFORMANCE TESTING Describes in detail in what way measurements shall be performed in order to get correct power curve for a wind turbine.	1982	1990	
2	ESTIMATION OF COST OF ENERGY FROM WIND ENERGY CONVERSION SYSTEMS States all the various elements and assumptions that enter a cost calculation.	1983	1994	
3	FATIGUE LOAD CHARACTERISTICS The correct procedure is described for getting a valid estimate of the fatigue life for the components of a wind turbine.	1984	1989	
4	MEASUREMENT OF NOISE EMISSION Noise being one of the potential nuisances caused by a wind turbine, the correct measurement of noise output is vital.	1984	1988	1994
5	ELECTROMAGNETIC INTERFERENCE This other possible source of disturbance caused by a wind turbine must be evaluated carefully and accurately.	1986		
6	STRUCTURAL SAFETY Outlines a rational procedure for setting up standards of safety.	1988		
7	QUALITY OF POWER The quality of the power output from a wind turbine needs to be described unambiguously.	1984		
8	GLOSSARY OF TERMS A comprehensive collection is compiled of the special terms used in the trade, with their proper definitions.	1987	1993	
9	LIGHTNING PROTECTION OF WIND TURBINE GENERATOR SYSTEMS	1997		
10	NOISE EMISSION MEASUREMENTS	1997		
11	POINT WIND SPEED MEASUREMENTS	in preparation		

Documents produced under Task XI, published by the Operating Agent, are available from the Operating Agent (Department of Energy Technology, Technical University of Denmark) and from representatives of countries partici-

pating in Task XI (Australia, Canada, Denmark, European Commission, Finland, Germany, Greece, Italy, Netherlands, New Zealand, Norway, Spain, Sweden, United Kingdom, and United States).

Table 2.2 List of Topical Expert Meetings Held Since 1978.

1	Seminar on structural dynamics	12 Oct 1978	Munich, Germany
2	Control of LS WECS and adaptation of wind electricity to the network	4 Apr 1979	Copenhagen, Denmark
3	Data acquisition and analysis for LS WECS	26-27 Sept 1979	Blowing Rock, USA
4	Rotor blade technology with special respect to fatigue design	21-22 Apr 1980	Stockholm, Sweden
5	Environmental and safety aspects of the present LS WECS	25-26 Sept 1980	Munich, Germany
6	Reliability and maintenance problems of LS WECS	29-30 Apr 1981	Aalborg, Denmark
7	Costing of wind turbines	8-19 Nov 1981	Copenhagen, Denmark
8	Safety assurance and quality control of LS WECS during assembly, erection and acceptance testing	26-27 May 1982	Stockholm, Sweden
9	Structural design criteria for LS WECS	7-8 Mar 1983	Greenford, UK
10	Utility and operational experience from major wind installations	12-14 Oct 1983	Palo Alto, California
11	General environmental aspects	7-9 May 1984	Munich, Germany
12	Aerodynamic calculation methods for WECS	29-30 Oct 1984	Copenhagen, Denmark
13	Economic aspects of wind turbines	30-31 May 1985	Petten, Netherlands
14	Modelling of atmospheric turbulence for use in WECS rotor loading calculations	4-5 Dec 1985	Stockholm, Sweden
15	General planning and environmental issues of LS WECS installations	2 Dec 1987	Hamburg, Germany
16	Requirements for safety systems for LS WECS	17-18 Oct 1988	Rome, Italy
17	Integrating wind turbines into utility power systems	11-12 Apr 1989	Herndon, USA
18	Noise generating mechanisms for wind turbines	27-28 Nov 1989	Petten, Netherlands
19	Wind turbine control systems—strategy and problems	3-4 May 1990	London, England
20	Wind characteristics of relevance for wind turbine design	7-8 Mar 1991	Stockholm, Sweden
21	Electrical systems for wind turbines with constant or variable speed	7-8 Oct 1991	Gothenburg, Sweden
22	Effects of environment on wind turbine safety and performance	16-17 June 1992	Wilhelmshaven, Germany
23	Fatigue of wind turbines, full-scale blade testing and non-destructive testing	15-16 Oct 1992	Golden, Colorado, USA
24	Wind conditions for wind turbine design	29-30 Apr 1993	Risø, Denmark
25	Increased loads in wind power stations (wind farms)	3-4 May 1993	Gothenburg, Sweden
26	Lightning protection of wind turbine generator systems and EMC problems in the associated control systems	8-9 Mar 1994	Milan, Italy
27	Current R&D needs in wind energy technology	11-12 Sept 1995	Utrecht, Netherlands
28	State of the art of aeroelastic codes for wind turbines	11-12 Apr 1996	Lyngby, Denmark
29	Aero-acoustic Noise of Wind Turbines	17-18 Mar 1997	Milano, Italy
30	Power Performance Assessments	8-9 Dec 1997	Athens, Greece

CHAPTER 3

Task XIV – Field Rotor Aerodynamics

Task XIV (also known as Annex XIV) was established to coordinate full-scale aerodynamic test programs on wind turbines in order to acquire the maximum experimental data at minimum cost. After more than four years of close cooperation among participating institutes, the task was completed in 1997 and a final report has been published which includes conclusions and recommendations arising from the work.

As a result of the project, a well-documented database has been created with aerodynamic measurements on all participating facilities. The database is accessible on an ftp site at ECN and on CD-ROM available from the Operating Agent. For parties not participating in the original Task, the data can be obtained under the condition that feedback will be delivered on the experiences with the database. So far a total of five parties have requested the database and accepted this condition.

Under this task a total of five full-scale aerodynamic test programs were coordinated by:

Delft University of Technology, DUT
Netherlands;

Imperial College, IC and Rutherford
Appleton Laboratory, RAL, United
Kingdom;

Netherlands Energy Research Foundation,
ECN, Netherlands (Operating Agent);

National Renewable Energy Laboratory,
NREL USA;

RISØ National Laboratory, Denmark.

In these full-scale test programs local aerodynamic quantities (forces, inflow velocities, inflow angles, etc) are mea-

sured at several radial positions along the blade. The local aerodynamic data these test programs supply is a major step forward in understanding the very complicated aerodynamic behavior of wind turbines. In conventional test programs only blade (or rotor) quantities are measured. Usually these quantities are integrated over the rotor blade(s) and they are not only influenced by aerodynamic effects, but also by mass effects. In this case the local aerodynamic properties of the blade can only be derived indirectly, introducing an uncertainty.

The work of Task XIV has been documented in *Final Report of IEA Annex XIV: Field Rotor Aerodynamics*, ECN-C-97-027, in June 1997. The report, written by J.G. Schepers et al, was published by the Netherlands Energy Research Foundations. The report contains the following series of conclusions and recommendations stemming from the work.

1. IEA Task XIV served as a platform where very specific knowledge associated with aerodynamic measurements could be exchanged. All participants agreed that this has been very instructive and has enabled the acceleration of their experimental programs.
2. A unique, well-documented database was developed in which detailed aerodynamic measurements are stored. About 125 time series of aerodynamic field measurements are available. The measurements are obtained on five very different wind turbine configurations. The diameter of these turbines ranges from 10 to 27 meters. Measurements have been supplied for very different conditions. As a result, more accurate aerodynamic models can be developed and validated.

3. In order to create the database, a joint measurement program was agreed upon. It was agreed that measurements should be supplied in which the angle of attack ranges from negative values to deep stall values. Also, measurements at yaw misalignment and at stand still have been supplied. The data file formats and the conventions have been harmonized in order to make the database easily accessible.
4. In interpreting the measurements and when comparing field data with wind tunnel experiments, it should be kept in mind that the definition of angle of attack, dynamic pressure, and aerodynamic coefficients is less straightforward than in the wind tunnel case. Several methods are applied by the IEA Task XIV participants for the determination of these quantities. Although the project results indicate that the mean angle of attack and dynamic pressure which result from the different methods yield a reasonable mutual agreement, the differences in standard deviations are considerable and more investigation on this subject is required.
5. There is a clear need to maintain the database. The objective of Task XIV was to develop the database, not to use it. Extensive use of the database in the near future and over the long term will identify "gaps" and methods to fill them. Furthermore, most of the experimental facilities that contributed to the database are still operational. Several very useful measurements are still expected and the storage of these data will definitely improve the quality of the database.
6. There is a clear need for the wind energy community to reach consensus about common conventions, definitions, notations, and reference systems for wind turbines. Within IEA Task XIV much effort had to be spent on the exact definition of wind turbine conventions, notations and reference systems. This item was essential in the present project where data from different institutes had to be harmonized. This required the participants to reprocess their data files. Several data exchange rounds were necessary before all participants supplied the measurements according to the common specifications.

CHAPTER 4

Task XV - Annual Review of Progress in the Implementation of Wind Energy by the IEA Member Countries

This Task was initiated on June 1, 1995, and will remain in force for a period of three years. It may be extended by agreement of two or more participants acting in the Executive Committee. ETSU, on behalf of the United Kingdom, is the Operating Agent for this Task.

4.1 OBJECTIVE

The objective of this Task is to produce an annual review giving an overview of the progress in the commercial development of wind turbine systems in the IEA member countries participating in this Agreement in a form suitable for presentation to decision makers in government, planning authorities, the electricity supply industry, financial institutions and the wind industry.

The aim is to identify major trends in initiatives and attitudes that are likely to be of interest to decision makers rather than to produce detailed statistics of installations and their performance.

4.2 MEANS

The annual review will be based on the annual national reports submitted to the Executive Committee. A summary of progress in the implementation of wind energy during 1997 is included in this Annual Report, and a full review will be published shortly afterwards as a stand-alone document, with references to the annual report, for those seeking more detailed information. A final report will be prepared after three years on completion of the Annex.

Participants

Denmark	The Ministry of Energy
European Commission	Directorate General XII
Germany	Forschungszentrum Jülich GmbH
Greece	The Ministry of Industry/Energy and Technology
Italy	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA); and ENEL, Società per Azione
Japan	The Government of Japan
Netherlands	The Netherlands Agency for Energy and the Environment (NOVEM)
New Zealand	Electricity Corporation of New Zealand (ECNZ)
Norway	The Norwegian Water Resources and Energy Administration (NVE)
Sweden	The National Board for Industrial and Technical Development (NUTEK)
United Kingdom	Department of Trade and Industry
United States	The Department of Energy

CHAPTER 5

Task XVI – Wind Turbine Round Robin Test Program

5.1 INTRODUCTION

International recommended practices for developing and testing wind turbines are being developed by the International Energy Agency (IEA). International norms and standards are being developed by the International Electrotechnical Commission Technical Committee 88 (IEC-TC88) and other agencies. When countries adopt these new standards, a mechanism should be in place to ensure that turbines are tested and certified to common criteria. Common criteria could enable different countries to accept foreign certification in lieu of their own.

However, countries have found that there can be discrepancies between tests conducted in different locations using different test equipment. A round robin test of anemometers demonstrated that even simple wind speed measurements can be significantly affected by different anemometer calibration procedures. Power curve, noise and load tests of full turbines for certification programs in different countries may reveal important differences. A basis for exchanging test reports should be established to demonstrate that these tests can be reliably conducted in different locations by different testing agencies and achieve similar results. Results from this demonstration would facilitate international certification harmonization efforts.

A series of round robin comparison tests at participating national laboratories and other interested test stations have been suggested as a means of validating test procedures and establishing reciprocity between different certification testing lab-

oratories. All participating laboratories will test identical machines at their own facilities, using comparable test instrumentation and data acquisition equipment. Discrepancies in the test data will be resolved and serve as the basis for improvements in testing procedures and calibration methods. This effort could also serve as justification for mutual recognition of foreign certification.

5.2 OBJECTIVES

The objectives of this program are to validate wind turbine testing procedures, analyze and resolve sources of discrepancies, and to improve the testing methods and procedures.

Task descriptions

- development of test and analysis plan;
- procurement and installation of test turbines;
- preparation of test sites;
- testing of standard turbines and data analysis.

Participants

- Risø Test Station for Wind Turbines, Denmark
- Italian Agency for New Technology, Energy and the Environment (ENEA), Italy
- Center for Renewable Energy Sources (CRES), Greece
- Atlantic Wind Test Site, Canada

National Renewable Energy Laboratory (NREL), United States of America The Operating Agent is the National Renewable Energy Laboratory (NREL) in the United States.

Status

This annex to the Wind Energy Agreement was approved with a starting date of April 1996. After the program kickoff meeting, in April 1996, participants began detailed preparations for testing. These included drafting of test plans, initiation of anemometer wind tunnel calibrations, and initiation of site calibration measurements.

Wind tunnel calibrations were conducted in cooperation with a European Wind Turbine Standards program, MEASNET, in which anemometers from eight countries are being calibrated in ten wind tunnels. Final calibrations have been completed.

NREL and Risø have completed site calibration measurements, which quantify wind speed differences between the anemometer tower and the wind turbine. Other participants plan to conduct site calibration tests in the near future.

The Standard Turbine is an AOC 15/50, a 50 k5free-yaw turbine that is relatively easy to transport and install. Participants will test three of these turbines, one at Canada's Atlantic Wind Test Site, one at the United States' National Renewable Energy Laboratory, and one at several European test stations. The first two turbines have been in operation for several years. AWTS engineers have been conducting operational tests of their turbine for several years. They plan to begin testing in accordance with procedures defined for this Annex later in 1998.

NREL staff have completed power performance and noise tests of their turbine. They expect to complete loads tests by June 1998.

The third turbine was shipped to Denmark and began operation at Risø in early December. Risø staff plan to complete tests by May 1998. At that time, the turbine will be shipped to ENEA for testing there in Autumn of 1998. Finally the

turbine will be shipped to CRES for testing in the Spring of 1999.

A status meeting was held at CRES in Greece on December 10, 1997, to discuss results to date, continue formalization of the test plan and plan the transfer of the Risø test turbine to the next test station in Europe. Another meeting is scheduled in June 1998 at the conclusion of NREL and Risø tests.

III. NATIONAL ACTIVITIES

Chapter 6



Overview

The National Reports in this volume describe in some detail the wind energy activities and developments in the individual countries. This overview collates the information given in the National Reports on the status of the industry. Where information relates to a specific country, its two letter national identification code is included in parentheses.

A full review comparing all aspects of national approaches to promoting the technology will be published in Summer 1998 as a stand alone document for those seeking a more detailed overview.

6.1 MARKET STIMULATION INSTRUMENTS

The main market stimulation instruments used in participating countries are investment subsidies, tax incentives, and payment of premium prices for the energy produced. All countries also offer support for industrial development in some form or another. The trend is towards the payment of a premium price for energy generated and away from investment subsidies.

The premium price is usually set in relation to the national electricity tariffs, except in the UK where a bid-in system is used and contracts are awarded to the lowest bidders. In a number of countries customers are being offered "Green Power" at slightly higher rates than electricity generated from conventional sources. This is providing another source of funding for wind energy projects.

6.2 MAIN CONSTRAINTS ON MARKET DEVELOPMENT

The primary constraint affecting market development is the low cost of conventional generation. This low cost is the

result of cheap fuel and surplus capacity, which makes wind energy economically unattractive where it has to compete on the open market (AU, CN, SE, JP, NZ, NO).

In countries where premium buy-back prices make the generation of electricity by wind power economically viable, the main constraint on the rate of development is the difficulty of obtaining planning consent for projects. Objections are often raised on the grounds of environmental concern, in particular the visual impact of wind farms (DK, DE, IT, NL, SW, UK, US).

6.3 COMMERCIAL IMPLEMENTATION OF WIND POWER

6.3.1 Installed Capacity

The annual installed capacity in the IEA countries rose in 1997 by 1241 MW compared to 880 MW in 1996, 863 MW in 1995, and 521 MW in 1994. This brought the total installed capacity in the countries to 6321 MW. The number of new turbines rose to 2252 (compared to 1796 in 1996, 1951 in 1995, and 1523 in 1994) as the trend to machines of higher rated capacity continued. The average rating of the turbines installed during 1997 was around 550 kW.

The annual installed capacities and numbers of turbines for all countries from 1994 to 1997 are shown in Table 6.1

The increase in average rated capacity over the last four years is apparent.

World-wide growth in wind energy installations is continuing. During 1997, the total capacity increased approximately 1420 MW to 7590 MW. This includes wind installations in countries that are not members of the IEA Wind Agreement, e.g., India with 933 MW and China,

169 MW. Growth was fastest in Europe although deployment is expected to increase in the United States during 1998.

6.3.2 Performance of Installed Plant

Electricity Generation

The aggregate numbers for generation for the participating countries was 10,900 GWh during 1997 compared to 8,500 GWh in 1996, 7,100 GWh in 1995, and 6,250 GWh in 1994.

Availability and Load Factors

Information on performance of installed plant continues to be sparse as few countries have a reporting system in operation and outside of these, the information is regarded as commercially sensitive. Most commercial plants are reported to be operating with availabilities of 97-99% and load factors as high as 0.45, depending on the wind speeds at the sites.

6.3.3 Operational Experience

In general the installed turbines performed well with few operational difficulties. Lightning strikes and icing resulting from extreme weather conditions were the main operational problems in some locations.

No major problem was reported on the integration of output into the electrical distribution systems. Large-scale integration was identified by several countries as a potential constraint on development in sparsely populated areas, although the benefits of embedded generation were also stressed.

6.4 ECONOMICS

6.4.1 Turbine Manufacturing and Project Costs

Ten of the reporting countries (AU, GR, MX, NO, NZ and SF excluded) have turbine manufacturing industries, while seven (US, DE, DK, ES, NL, SW, UK) have more than 100 MW of plants in operation. In these seven countries, good estimates

of manufacturing, project, and generation costs can be made.

During 1997, the ex-factory costs of turbines fell slightly from the 1996 levels. This reduction in costs was probably due to the increased demand and reduced production costs per rated kW as the size of turbines increased. In 1997, the reported prices ranged from USD 670-960 per rated/kW with an average of around USD 800/kW.

Total average project costs also decreased in 1997 compared to 1996, however there is wide variation in costs from USD 880 to 1430 per installed kW. The overall average total project cost was around USD 1,080/installed kW. The range of these costs results from variations in the difficulty of the terrain where the wind farm is installed and variations in the ease of access to the electricity network.

Currency exchange rates can also have a significant effect on project costs in countries where the majority of turbines are imported.

6.4.2 Invested Capital

The capital investment in commercial wind power can be calculated from the installed capacity and estimated total project costs per installed kilowatt. If we assume that plants installed during 1997 cost an average of USD 1,040 per installed kW, that plants installed in 1996 cost USD 1,200/kW, and that plants in all other years cost USD 1,350 per installed kW (which is recognized as being only indicative), the aggregate investment in wind energy generation by the reporting countries is very approximately USD 1,340M during 1997 and USD 8,100M in total.

6.5 MANUFACTURING INDUSTRY

6.5.1 Status of Manufacturing Industry

The status of the wind turbine manufacturing industry in the individual countries

depends strongly on the internal program of installation of capacity as most countries see wind power as an opportunity to develop an industrial manufacturing capability and use a high proportion of nationally produced machines. Thus the manufacturing industry flourishes most strongly in DE, IT, NL, ES, and US. The industry is even stronger in DK which has an internal installation program and also exports turbines to many countries, both in the IEA regions and elsewhere.

6.5.2 Technical and Business Developments

The trend of turbines with higher rated capacity for the commercial market continued during 1997. The 600/750 kW machines were further refined and manufacturers began producing commercial machines rated at or over 1 MW. Smaller machines continued to be developed ("advanced machines"), usually through value engineering to make them lighter and more cost competitive.

6.5.3 Supporting Industries

As more wind turbines are sold, the market becomes more buoyant for component manufacturers, especially as local sourcing of components is regarded favorably in several countries.

6.6 GOVERNMENT-SPONSORED R, D&D PROGRAMS

6.6.1 R,D&D Funding

There are government-sponsored programs in all the countries participating in IEA R&D Wind. They are funded by the central government through government departments or agencies, or funded and managed by government-owned companies. The reported 1997 annual budgets for direct R&D work, excluding support for large-scale demonstrations, range from countries that spend less than one million USD (AU, CN, SF, MX, NZ, NO, SW), through countries that spend between one

and 10.2 million USD (DK, DE, GR, IT, JP, NL, ES, UK) to the United States which spends 28.6 million USD on wind energy R&D.

In Europe, overall R&D funding levels are actually higher than these values indicate because additional funding for wind energy R&D is available through the European Union which, of course, originates from the contributions of the individual national governments. The 1997 national funding levels show only small changes compared to those of 1996.

6.6.2 Priorities

The main R,D&D priorities reported by each country can basically be divided into two categories. The first is concerned with national issues, such as the available resource and the impact of turbine siting. The second is concerned with the development of the technology itself. Topics of interest include:

National Issues

- Resource evaluation (wind measurements, modeling)
- Planning consent (siting of turbines)
- Environmental impact (noise, visual intrusion)
- Electrical issues (integration, power quality)
- Standards and Certification.

Technology Development

- Improved efficiency (aerodynamics, variable speed operation)
- Cost reductions (value engineering, component development)
- Advanced turbine development (new concepts)
- Safety (structural loads)

In general, work on national issues is directed by government departments or agencies while technology development is undertaken in collaboration with, and often partially funded by, industry.

6.6.3 New R, D&D Developments

The main trends in turbine development during 1997 continued to be towards using lighter, more flexible turbines, using direct drive generators, and using variable speed operation. The industry continued to develop turbines with higher rated capacities for the commercial market. Specific new concepts under development are described in the individual national reports.

6.6.4 Offshore Siting

Interest in siting turbines offshore is limited to those countries where there is a shortage of suitable sites on land (IT, SW) or where population density precludes extensive on-land development because of environmental intrusion (DK, NL, UK). By the end of 1997, Denmark had two offshore wind farms of 5 MW in operation, while the Netherlands (4 x 500 kW) and Sweden (1 x 220 kW, 5x500 kW planned) had mounted demonstration projects. Both Denmark and the Netherlands have announced sizeable targets for offshore deployment.

6.6.5 International Collaboration

There is strong multi-national collaboration in Europe for R,D&D through numerous JOULE and THERMIE projects which are partially funded by the European Union. The United States and Denmark have bilateral technical assistance agreements with several countries. In seeking to establish overseas trade, most countries are actively seeking collaboration with countries that have large potential markets (e.g. India, China and South America).

Table 6.1 Annual Installed Capacities and Numbers of Turbines for IEA R&D Wind Countries, 1994–1997.

COUNTRY	ANNUAL INSTALLED CAPACITY (MW)				ANNUAL NUMBER OF MACHINES INSTALLED			
	1994	1995	1996	1997	1994	1995	1996	1997
Australia		0	0	1.05		0	1.0	3.0
Canada	18.9	0.6	0.2	3.0	54.0	1.0	2.0	5.0
Denmark	52.0	98.0	169.0	300.0	142.0	199.0	343.0	533.0
Finland	0	1.8	0.9	4.6	0	4.0	2.0	8.0
Germany	309.0	505.0	428.0	534.0	834.0	1070.0	808.0	849.0
Greece	0.7	0.7	0	3.0	3.0	2.0	0	3.0
Italy	10.2	0.6	48.4	28.5	36.0	1.0	105.0	56.0
Japan	0.9	3.6	4.0	6.5	6.0	13.0	16.0	19.0
Mexico	1.6	0	0	0	7	0	0	0
Netherlands	22.0	100.0	47.0	44.0	93.0	255.0	129.0	90.0
New Zealand	0	0	3.5	0	0	0	7.0	0
Norway	0	0	0	0	0	0	0	0
Spain	23.4	47.0	96.5	205.0	86.0	149.0	220.0	477.0
Sweden	7.0	28.8	38.0	17.0	28.0	62.0	84.0	37.0
United Kingdom	33.0	35.1	36.8	84.5	74.0	71.0	66.0	152.0
United States	42.0	41.6	7.2	11.0	160.0	124.0	13.0	20.0
Totals	521.0	863.0	880.0	1241.0	1523.0	1951.0	1796.0	2252.0
Average (MW)					.34	.44	.49	.55